Coastal and Near Surface Mixing

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LONG-TERM GOAL

My long-term goal is to contribute to our understand of turbulence and mixing processes in the ocean and how these affect the transport of heat, salt, and other important scalars. Of particular interest to me is relating the mixing processes to the strength of currents and density stratification.

OBJECTIVES

I wish to establish how the efficiency and the rate of mixing depend upon the vertical shear of currents, the strength of the density layering and the intensity of turbulence in the ocean. Mixing increases the potential energy of the ocean by raising its density surfaces. The efficiency of mixing is the fraction of kinetic energy that is converted to potential energy. The challenge is to measure the mixing directly without relying on models and assumptions about the nature of turbulence.

APPROACH

We are using a towed vehicle to survey the turbulence in deep tidal channels where, over the course of a tidal cycle, currents, stratification and the intensity of turbulence vary considerably. The towed vehicle (Fig. 1) carries high-resolution velocity and temperature sensors (shear probes and thermistors), current meters, a vertical array of three pairs of salinity and temperature sensors, and motions sensors. These sensors provide a measure of the density stratification, the rate of dissipation of turbulent kinetic energy by friction, and the fluctuations of vertical velocity, salinity and temperature due to turbulent eddies. Simultaneously, we measure the vertical gradient of current using a ship-mounted acoustic current sensor (ADCP) and take profiles of salinity, temperature and density over the full water column using a CTD. The correlation of the fluctuations of vertical velocity with temperature and salinity provides a direct estimate of the vertical flux of density (hence the rate of mixing) without making any assumptions about the nature of turbulence. The ratio of this flux to the rate of dissipation of kinetic energy gives the efficiency of mixing.

The rate and efficiency of mixing each depend upon the buoyancy Reynolds number (which is measured with the towed vehicle) and the Richardson number (which requires additional data from the ADCP). Both of these parameters vary by several factors of 10 over a tidal cycle and this should allow us to determine how they relate to the rate and efficiency of mixing.

WORK COMPLETED

We have completed the first cruise to Sansum Narrows (July 1999) and collected a total of 40 hours of data from 4 tows through this channel. Each tow lasted about 10 hours and consisted of two trips up and down the channel. Our 600kHz ADCP profiled the full water depth (75-100 m) in most of the channel and bottom tracked in all parts of the channel. Teething problems with deployment and recovery where overcome. We made continuous up-down casts with the CTD while towing but not during all tows due to problems with winch hydraulics. The towed vehicle carried four shear probes two of which were the new miniature (half-size) types.

RESULTS

We have verified that the mixing intensity, indicated by the rate of dissipation, ranges from 10^{-9} to 10^{-4} W kg^{-1} and that the Richardson number was between 0.01 and 2 during the tows. Large eddies were visually observed in the channel and the vertical array of temperature and salinity sensors on the tow vehicle frequently indicated overturning motions. We have also compared the spectra of velocity fluctuations of the regular and miniature probes and verified that the latter has twice the spatial resolution of the former. We have processed some of the inertial navigation information and checked that vehicular motions are small +- 0.05 m/s. Data processing is still in its early stage and only very preliminary results are available at this time.
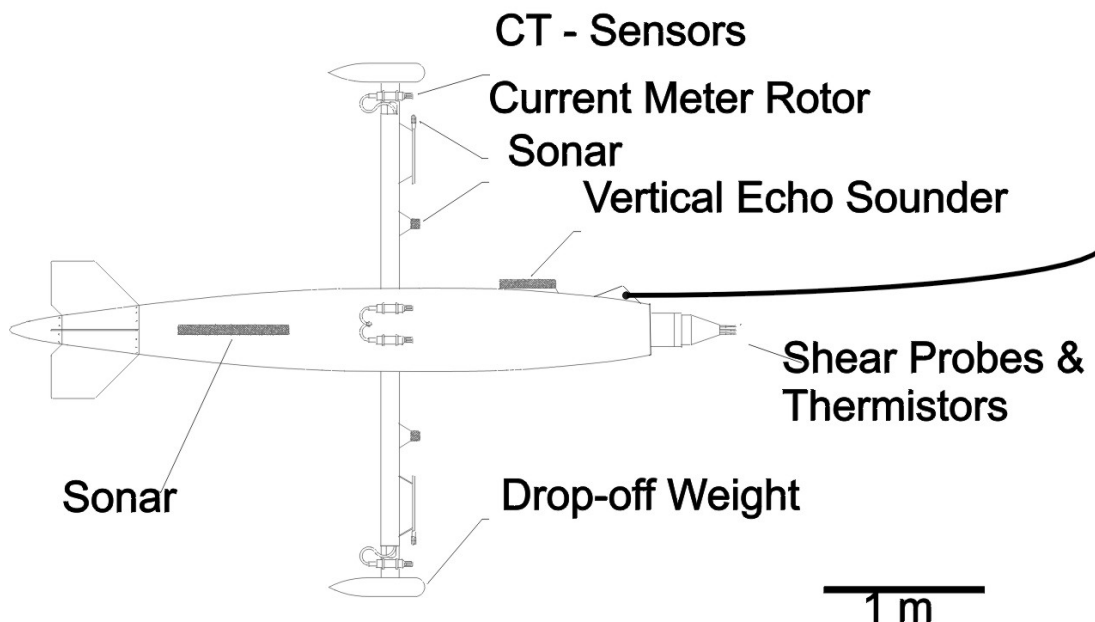

Fig. 1. The towed vehicle sketched used for the study of mixing in Sansum Narrows. The acoustic transducers were not mounted. The conductivity (salinity) and temperature sensor at mid body was mounted close to the shear probes for one of the tows. The vehicle weighs 900 pounds in air and has an enclosed mass 800 kg when submerged.

IMPACT/APPLICATION

Simultaneous measurements of the fluctuations of vertical velocity and temperature combined with dissipation rates and stratification have never before been made from a single instrument in a tidal channel. Our approach derives the heat flux directly and lends itself to the mixing in other environments and with other horizontally moving platforms such as autonomous underwater vehicles (AUV)s, submarines and possibly moorings. It provides a means to study the complicated motions in coastal environments resulting from strong currents that contact the bottom (for example, Fig. 2). The insight to mixing obtained from these and future measurements will lead to better predictions about coastal dynamics such as, for example, the dispersion of contaminants and the diffraction and scattering of high-frequency sound.
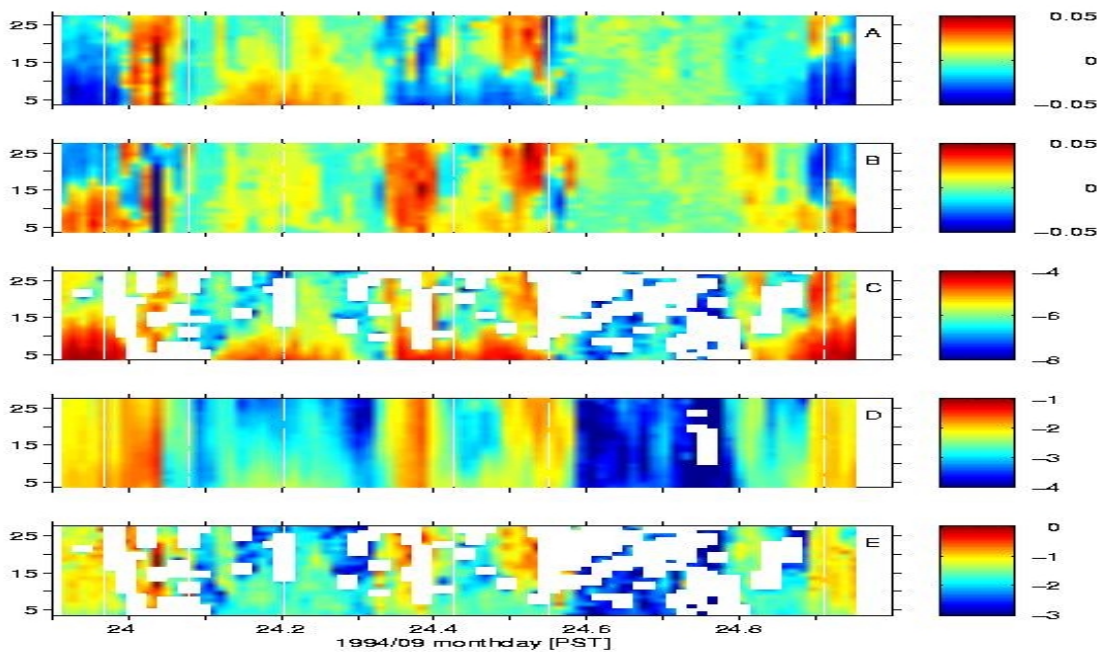
Fig. 2. One day of turbulence data collected in a tidal channel 30 m deep and peak currents of 1 m/s using a 600kHz ADCP. The vertical axis indicates the height above the bottom (m) while the horizontal axis gives the time in days. The top panel (A) indicates the turbulent friction in the along-channel direction (in units of m/s). Friction is largest near the bottom and it is directed along the current (warm shades during the flood and blue during the ebb). The cross-channel friction (Panel B) is weak during flood but comparable to the along channel friction during the ebbs. The rate of production of turbulent kinetic energy (Panel C) is highly bottom intensified and follows the tide closely. It is intermittently important throughout the water column. The turbulent kinetic energy (Panel D) is vertically more homogeneous than its rate of production and is very low during the weak ebb on day 24.7. The eddy viscosity (Panel E), which relates the friction to current shear, is fairly steady near the bottom (~0.01 m^2/s) but quite variable at mid-depth and higher. The scales for panels C-E are base-10 logarithmic. (From Lu and Lueck 1999).

TRANSITIONS

The methods and techniques used for this research have been transferred to autonomous underwater vehicles and are being used on ONR-funded projects to study environmental processes over the continental shelf (Ed Levine, NUSWC, Newport) and in the Florida Current (Manhar Dhanak, Florida Atlantic University). Our data processing techniques are also used by these two and by other researchers supported by ONR.

RELATED PROJECTS

1. Hide Yamazaki of the Tokyo University of Fisheries and I are investigating shear instability and internal-wave breaking near the bottom of the mixing layer and mixing induced by ridges crossing the Kuroshio Current south of Tokyo.
2. Ed Levine of the Naval Undersea Warfare Center and I are using the small autonomous vehicles *REMUS* to study mixing processes in the New Jersey Bight and Massachusetts Bay.
3. I am also working with Tom Osborn (Johns Hopkins) and Steve Thorpe (South Hampton, UK) on using the AUV *Autosub* to examine gravity currents on the continental slope.

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